TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 14, No. 3, June 2015, pp. 455 ~ 469
DOI: 10.11591/telkomnika.v14i3.7938

Design and Implementation of Embedded Processor Based Brushless Motor Drive using Lead Acid Battery as Source with Lithium Ion Capacitor

Sathish kumar Shanmugam*[1], Meenakumari Ramachandran[2]
[1]Jansons Institute of Technology, Coimbatore, India
[2]Kongu Engineering College, Erode, India
*Corresponding author, e-mail: sat_meae2k5@rediffmail.com

Abstract

For the past two decades, Brushless DC motor has become more efficient and robust motor in industrial applications due to their simplicity in structure, reliability, good mechanical properties. The absence of brushes features these motors similar to AC motors whereas their speed performance is nearly equal to that of the DC motors. Thus the combined advantages of AC and DC motors make these motors more efficient in various applications. The use of these machines in different fields such as aerospace, robotics, electric vehicles, etc., requires wide range of speed control. The Converter selected for the Brushless DC Motor is the PWM Inverter. The design was based on the output equation similar to that of conventional dc machines. This generates high-resolution PWM outputs, used to control the switching pattern of the BLDC Inverter. By varying the PWM signal produced from the microcontroller, the speed of the motor can be varied. The Hall Effect sensing unit gives information about the rotor position and based on this rotor information, switching sequence of the MOSFET is decided. The firing pulses to the gate of the MOSFET are given by the Control Signal Generation Module. Based on the developed model simulation studies are performed in Matlab/Simulink environment and hardware implementation of BLDCM drive using Lead acid battery as source With Lithium ion capacitor system is done and results were analysed using Digital Scope Oscilloscope (DSO) and output were Carried Out Sucessfully.

Keywords: *sepic converter, MOSFET, BLDC motor, power conveter, PIC microcontroller*

1. Introduction

In BLDC Motor the SEPIC converter is used to boost the input voltage from 12 volt DC to 24 volt DC. A SEPIC is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0V.In SEPIC converter the voltage drop and switching time of diode is critical to a SEPIC reliability and efficiency. Schottky diodes be used too rweduce the spikes. Then this DC output is given to the voltage source inverter where the DC voltage is converted into AC voltage. The gate pulses are generated from the driver unit and it is given to inverter switches. The inverter output of AC supply is used to drive the BLDC motor. The controller chosen in this paper is PIC Microcontroller. This generates high-resolution PWM outputs, used to control the switching pattern of the BLDC Inverter. By varying the PWM signal produced from the microcontroller, the speed of the motor can be varied. The single phase AC supply of 230 V, 50 Hz is the input source and it is given to the step down transformer. Then the step down voltage is given to voltage regulator where it regulates the voltage and it gives the 5 volt and 15 volt regulated DC voltages. The 5 volt regulated DC voltage is given to the driver unit. Similarly the 15 volt regulated DC voltage is given to the PIC microcontroller unit. The power which is got from the solar module is stored in the batteries and is used to drive the BLDC motor. The 12 volt battery is used for hardware implementation purpose. In this Research, the battery bank is designed by connecting two 6 volt batteries in series to get 12 volt. Single-ended primary-inductor converter (SEPIC) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its

Received February 10, 2015; Revised April 28, 2015; Accepted May 7, 2015

input; the output of the SEPIC is controlled by the duty cycle of the control transistor. A SEPIC is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0V.In SEPIC converter the voltage drop and switching time of diode is critical to a SEPIC reliability and efficiency. The diode's switching time needs to be extremely fast in order to not generate high voltage spikes across the inductors, which could cause damage to components. Fast conventional diodes or Schottky diodes may be used. The function of an inverter is to change a DC input voltage to AC output voltage of desired frequency and magnitude. In case of 3-phase inverter, the inverter circuit changes DC input voltage to a symmetrical AC output voltage of desired magnitude and frequency. An opto-isolator, also called an opto coupler, photo coupler, or optical isolator, is a component that transfers electrical signals between two isolated circuits (here PIC microcontroller unit and driver unit) by using light. In this project opto isolator is also used to block over voltages, so that surge a one part of system will not destroy the other part of the system.PIC microcontrollers (Programmable Interface Controllers), are electronic circuits that can be programmed to carry out a vast range of tasks. The PIC 16F877A issued to control the voltage source inverter switches to control the speed of the BLDC motor. Brushless DC electric motor (BLDC motors, BL motors) also known as electronically commutated motors are synchronous motor that are powered by a DC electric source via an integrated inverter , which produces an AC electric signal [1, 2] to drive the motor. For hardware implementation 24 volt rating motor is used.

2. Research Method

The Figure 1 shows the block diagram of the Embedded system based BLDC motor drive for commercial applications. For hardware implementation a 12 volt battery is used. This 12 volt DC is given to the SEPIC converter.

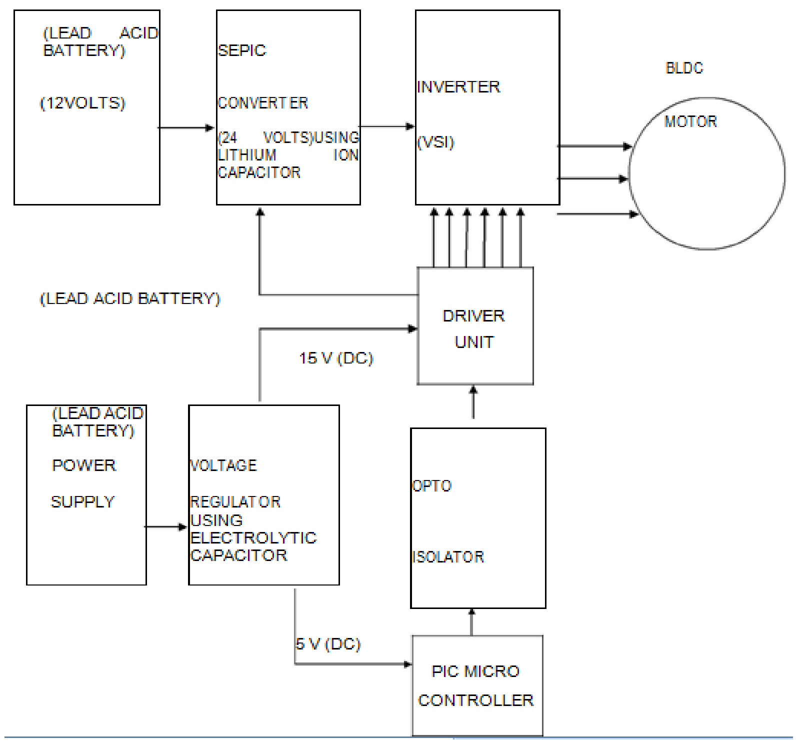

Figure 1. Block diagram of Embedded system based BLDCM drive

Brushless motors consist of a stationary part, the stator and a rotating part, the rotor. The space between the stator and the rotor is called the air gap. The stator carries the windings and the rotor carries the magnets. Brushless motors can have inside rotors called“In runner” or outside rotors called “Out runner”. In either case the stator windings are stationary, allowing direct winding access without brushes or slip rings.In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. Even though conventional DC motors are highly efficient, it had some drawbacks due to commutator and brushes which need proper maintenance. But in BRUSHLESS DC MOTOR when the functions of commutator and brushes were implemented by solid- state switches, maintenance free motors were realized. Instead of commutating the armature current by using brushes, here electronic commutation is used. This eliminates the problems associated with the brush and the commutator arrangement, thereby, making a BLDC more rugged as compared to a DC motor.Brushless DC Motor is a rotating electric machine where the stator is a classic three phase stator like that of an induction motor and the rotor has surface mounted permanent magnets. The BLDCM is driven by rectangular strokes coupled with the given rotor position. The generated stator flux interacts with the rotor flux, which is generated by a rotor magnet that defines the torque and the speed of the motor. The voltage strokes must be properly applied the two phases of three phase winding system, so that the angle between the stator flux and rotor flux is kept close to 90 degree.BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotate at the same frequency. BLDC motors do not experience the slip that is normally seen in Induction motors.

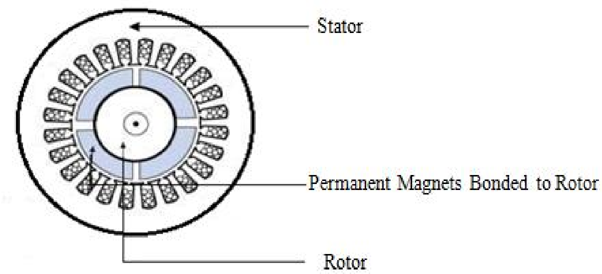

Figure 2. Cross Sectional View of BLDC Motor

BLDC motors are come in single phase, 2-phase and 3-phase configurations are shown in Figure 2. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. Three-phase motors have a number of slots (and teeth) that are evenly divisible by three. A phase is an individual group of windings with a single terminal accessible from outside the motor. Most brushless motors are three-phase. Each individual loop of wire making up a phase winding is called a turn.

The stator of a BLDC motor consists of stacked steels laminations with windings placed in slots that are axially cut along the inner periphery. Traditionally, the stator resembles that of an Induction motor. However, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion.Each of the windings are constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings are distributed over the stator periphery to form an even number of poles. There are two types of stator windings variants:

a) Trapezoidal motors
b) Sinusoidal motors

This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF). The Trapezoidal motor gives a back EMF in trapezoidal fashion and the sinusoidal motor gives a back EMF in sinusoidal as shown in the below Figure 3 & 4. In addition to the back EMF, the phase current also has trapezoidal and sinusoidal variations in the respective types of motor. Depending upon the control power supply capability, the motor with the correct voltage rating of the stator can be chosen.48 V, or less than that voltage rated motors are used in automotive, robotics, small arm movements etc. Motors with 100 V or higher than that ratings are used in appliances, automation and in industrial applications.The stator of the PMBLDC motor is made up of steel stampings with slots in its interior surface. These slots accommodate either a closed or open distributed armature windings. Traditionally, the stator resembles that of an induction motor; however. The windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings is constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings is distributed over the stator periphery to form an even number of poles.

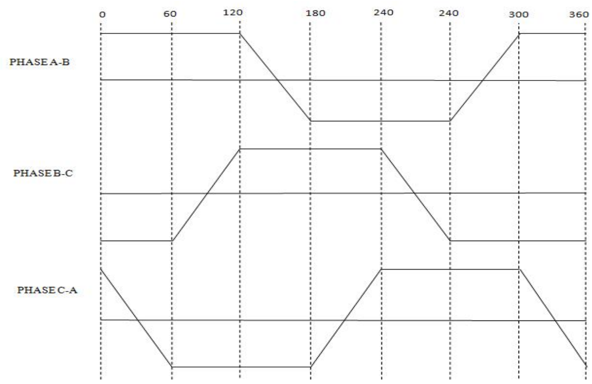

Figure 3. Trapezoidal Back EMF

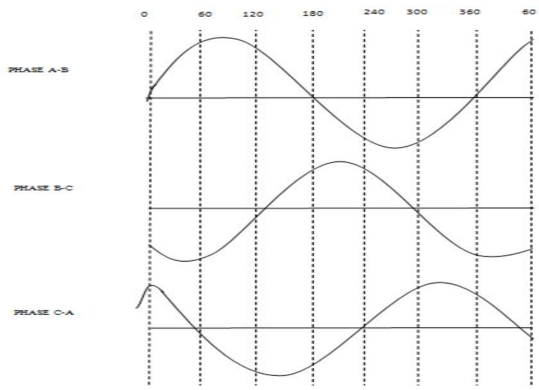

Figure 4. Sinusoidal Back EMF

LDC motor‟s rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor.The rotor shaft carries a rotor position sensor. The position sensor provides information about the position of the shaft at any instant to the controller which sends signal to the electronic commutator.

2.1. Conventional Working Block Diagram of BLDC Motor

The Brushless DC Motor is a combination of a Permanent Magnet AC Motor and an Electronic Commutator. In BLDC motor inverter has to replace the commutator of a conventional DC motor as shown in Figure 5.

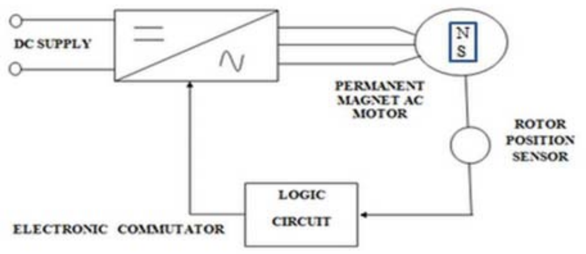

Figure 5. Functional Block Diagram of BLDC Motor

Brushless dc motor =Permanent magnet ac motor + Electronic commutator

The commutator acts like a three phase frequency converter. The commutation of a brushless DC motor depends upon the position of the rotor. The angle between the magneto - motive force of stator and magneto – motive force of rotor is fixed to 90 degrees (electrical). There are several methods to convert DC to AC. They differ mainly in their approximation to a perfect sinusoidal signal. As one would expect the best approximation yields the best transfer of power to a device that expects a sinusoidal signal.The applied DC voltage is supplied to the inverter block, thereby it converts DC to AC. The inverter is a six-step current inverter in which one of the phases is conducted eventually for 120 degree of the cycle. It is connected to the stator winding of the BLDC motor.Rotor Position Sensor is used to sense the position of the rotor of the BLDC motor. Hall Effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall Effect sensors are used for proximity switching, positioning, speed detection, and current sensing in BLDC motor drive.Hall sensors are commonly used to time the speed of wheels and shafts, such as for internal combustion engine ignition timing, tachometers and anti-lock braking systems. They are used in brushless DC electric motors to detect the position of the permanent magnet. Hall sensors can be used to operate as a switch. Its cost is less than other mechanical switches. It is also used in the brushless DC motor to sense the position of the rotor and to switch the transistor in the right sequence.

2.2. Commercial Applications

BLDC motors fulfill many functions originally performed by brushed DC motors, but cost and control complexity prevents BLDC motors from replacing brushed motors completely in the lowest-cost areas. Nevertheless, BLDC motors have come to dominate many applications, particularly devices such as computer and hard drives and CD/DVD players. Small cooling fans in electronic equipment are powered exclusively by BLDC motors. They can be found in cordless power tools where the increased efficiency of the motor leads to longer periods of use before the battery needs to be charged. Low speed, low power BLDC motors are used in direct-drive turntables for gramophone records.

High power BLDC motors are found in electric vehicles and hybrid vehicles. These motors are essentially AC synchronous motors with permanent magnet rotors. The Segway Scooter and Vectrix Maxi-Scooter use BLDC technology. A number of electric bicycles use BLDC motors that are sometimes built into the wheel hub itself, with the stator fixed solidly to the axle and the magnets attached to and rotating with the wheel.There is a trend in the HVAC and refrigeration industries to use BLDC motors instead of various types of AC motors .The most significant reason to switch to a BLDC motor is the dramatic reduction in power required to operate them versus a typical AC motor.While shaded-pole and permanent split capacitors motors once dominated as the fan motor of choice, many fans are now run using a BLDC motor. Some fans use BLDC motors also in order to increase overall system efficiency.The application of brushless DC (BLDC) motors within industrial engineering primarily focuses on manufacturing engineering or industrial automation design. In manufacturing, BLDC motors are primarily used for motion control, positioning or actuation systems. BLDC motors are ideally suited for manufacturing applications because of their high power density, good speed-torque characteristics, high efficiency and wide speed ranges and low maintenance.

2.3. Modeling of BLDC Motor Drive

Computer simulation plays a great role in research to analyze the behavior of new circuits, which leads to improved understanding of the circuit. In industry, they are used to shorten the overall design process [6, 7], since it is usually easier to study the influence the parameter on the system behaviour in simulation, as compared to accomplishing it in the laboratory on the hardware breadboard.The simulation is used to calculate the circuit waveform, the dynamic and steady state performance of the system, voltage and current rating of various components. Simulink is an interactive tool for modeling, simulating and prototyping analog and mixed signal system using the block sets rather than the line of code. MATLAB/Simulink platform is being used in industries also to simulate algorithms and evaluate alternatives early in the design process and convenient tool for monitoring simulation results.When DC supply is switched on to the motor the armature winding draws a current. The current distribution within the stator armature winding depends upon rotor position and the device is turned on. An EMF perpendicular to permanent magnet field is set up. Then the armature conductors experience a force. The reactive force develops a torque in the rotor. If this torque is more than the opposing frictional and load torque, the motor starts. It is a self starting motor.As the motor picks up speed, there exists a relative angular velocity between the permanent magnet field and the armature conductors. As per Faradays law of electromagnetic induction, an EMF is dynamically induced in armature conductors.This back EMF as per Len’s law, opposes the cause (i.e) armature current and is reduced. As a result the developed torque reduces. Finally the rotor will attain a steady speed when the developed torque is exactly equal to the opposing frictional load toque. Thus the motor attains a steady state condition.When the load-torque is increased, the rotor speed tends to fall. As a result the back EMF generated in the armature winding tends to get reduced. Then the current drawn from the mains is increased as the supply voltage remains constant.More torque is developed by the motor and it will attain a new dynamic equilibrium position when the developed torque is equal to the new load torque. Then the power drawn from the mains V*I is equal to the mechanical power delivered.

2.4. General BLDC Motor Equation

2.4.1. Voltage Equation

The voltage equation is given as

$$V_{dc} = 2[R_s I_a + (L-M)\, dI_a/dt] + e_1 - e_2 = R_a I_a + L_a\, dI_a/dt + e_1 - e_2 \quad (1)$$

Where:
V_{dc}= Voltage of the DC supply, V.
R_s= Stator winding resistance, Ω/ph.
I_a=Armature current, A.
L=Self Inductance of stator winding per phase, H. M=Mutual Inductance between two stator phases, H. e_1=Back EMF of the first current-carrying phase winding, V.
e_2=Back EMF of the second current-carrying phase winding, V.

The resultant EMF across the two phase windings is proportional to the motor speed. Hence the above voltage equation can be written as:

$$V_{dc} = R_a I_a + L_a\, di_a/dt + K_b \omega \quad (2)$$

2.4.2. General Torque Equation

The electromagnetic torque is proportional to stator current and is given by:

$$T_e = K_b I_a \quad (3)$$

The load torque which varies with motor speed is given by:

$$T_L = K_T \omega \quad (4)$$

The mechanical equation of the rotor is:

Te- TL=J d ω/d t+ B ω (5)

Substituting Equation (3) and (4) into Equation (5) we get:

Kb I a- K T ω=J d ω /d t + B ω (6)

Where,
Kb=EMF constant of the motor, Vs/ rad (Nm/A).
ω= Mechanical speed of the rotor, rad /s.
Te=Electromagnetic torque developed by the motor, Nm.
TL=Load Torque, Nm.
KT=Load Torque constant, N ms /rad.

The equations discussed here are used to develop the parameter blocks. To trigger the switches of the inverters, PWM signals are used. To obtain the position of therotor of the BLDC for getting the appropriate switching sequence, the rotor position sensors, i.e. hall sensors are mounted on the shaft of the rotor.The hall signals generated by these sensors will be in correspondence with that of the rotor position. A switching sequence is generated using the hall signals and the PWM signals are used to trigger the correponding switches of the inverter.

2.5. Simulation Model of BLDC Motor

The BLDC motor has to be equipped with a position sensor which informs the controller what the position of the rotor magnetic pole is, with respect to the particular stator phase winding. This is done in order to switch the motor ON and OFF [7]. The position sensors used that are usually optical and Hall sensor. The encoder will act as a position sensor, in the experiment carried out in this Research. The mathematical model of BLDC motor is shown in this section. The stator of a BLDC motor is similar to that of a poly phase AC induction motor. The function of the magnet in the rotor is to ideally fix the air gap flux density. The stator windings are distributed in nature. Since BLDC motor drive is a special machine, an inverter is required for its operation. A typical BLDC drive consists of a Voltage source inverter, BLDC motor and rotor position sensors for finding the rotor position after every switching sequence of the inverter. The induced voltages and currents in a BLDC motor drive are trapezoidal in nature. The Figure 6 shows the simulation model of BLDC Motor drive and the mathematical equations that are modeled are incorporated in the SIMULINK block diagram and the characteristics of the motor are studied from the output waveforms of simulation. The simulation of the BLDC drive is discussed in this model.

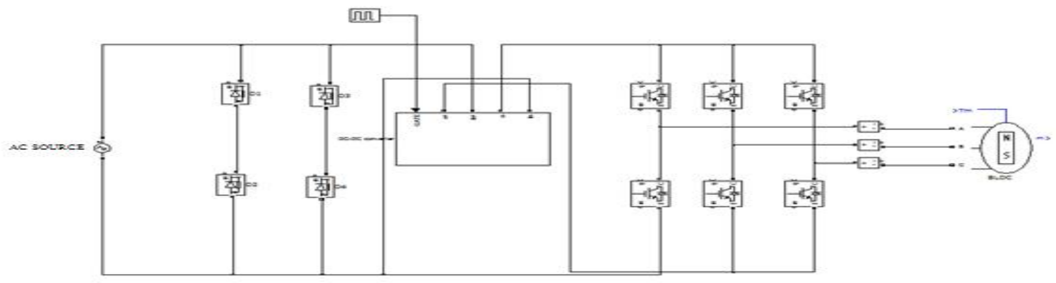

Figure 6. Simulation Model of BLDC Motor

The BLDC motor fed from a DC source through a standard three phase inverter bridge. Two switches should be conducting for every pattern, one from lower leg and another from upper leg resulting in alternate excitation of two phases at a time out of three phases which facilitates continuous rotation of the rotor. In BLDC motors, the field is generated by permanent magnets mounted on the rotor, and the rotating field is generated by means of stator windings. While no power is required for field excitation, leads to elimination of rotor losses.

2.6. Proposed General Circuit Diagram of BLDC Motor

Figure 7 shows the block diagram for a 3-phase BLDC drives, which consists of a 3-phase inverter and a BLDC motor. The 3-phase inverter uses a signal generated by the microcontroller to trigger the power device to produce necessary current in the motor winding for rotor shaft rotation.

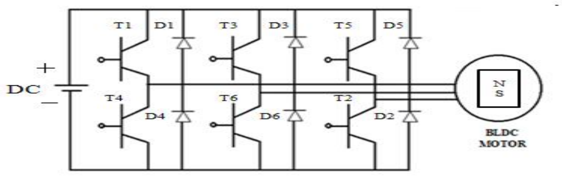

Figure 7. BLDC Motor Circuit

The inverter is controlled by PWM switching schemes to drive the BLDC motor. The gating signals of MOSFET are shifted by 60º by each gate to obtain a 3-phase balanced fundamental voltage with 120º phase shift. The setting of the conduction period is done by programming the desired on time of the MOSFET onto the microcontroller. There are several ways to modulate the motor drivers. We could switch the high and low side drivers together, or just the high or low driver while leaving the other driver on. Some high side MOSFET drivers use a capacitor charge pump to boost the gate drive above the drain voltage. Even though this application does not use the charge pump type drivers, we will modulate the high side driver while leaving the low side driver on. There are three high side drivers, any one of which could be active depending on the position of the rotor. PWM is one of the switching techniques widely used in controlling the output of the inverter especially in overcoming the harmonics problem. It is known that PWM method can moved the unwanted frequency component to a higher frequency region. Conventional method of generating PWM signal is by using a high ratio of carrier frequency signal and fundamental frequency signal generated via analogue circuit. Advancement in the digital technology enables PWM switching schemes to be generated using digital controller (i.e. micro controller). Through this technique, the harmonics content of the output voltage can be minimized and reduced significantly by simply adjusting the switching angles of the pulses using the programming language. Besides, generating PWM using digital controller ensures the signal remains digital all the way from the processor to the control system. The Pulse Width Modulation (PWM) switching schemes has become the essence of adjusting speed in motor drives system. These switching schemes can vary the magnitude of the voltage across the terminals of the loads and speed of the rotor shaft. It is also known that, the unwanted frequency component can be moved to a higher frequency region by means of several PWM switching schemes.Generally, there are two types of PWM modes operation namely PWM voltage mode and PWM current mode. PWM voltage mode derives its control signal from the output voltage of the switching converter. Meanwhile PWM current mode utilizes both the output voltage information as well as current information from the inductor in the switching converter to determine the desired duty cycle applied to the switching transistor. The implementation for PWM current mode is quite difficult compared with the PWM voltage mode.The ideal PWM switching strategy for power electronics converter is the one that can achieve the maximum possible voltage or current transfer ratio for a given converter, generating minimum low-order harmonic and creating minimum switching losses. The switching schemes are used for the gating signal of the Voltage Source Inverter (VSI) which is commonly used to drive the BLDC motor. Using the PWM switching scheme, several parameter can be adjusted to generate the desired voltage and frequency to the load.

2.7. PI Controller Design Involved in Proposed Research Model

PI is a feedback controller which drives the plant to be controlled with a weighted sum of the error and the integral of that value. PI controllers are widely used inindustrial application, due to their simplicity, low cost and robustness. These controllers can also be implemented easily through analog components. The general operation of PI can be represented by the following equation.

$M(t)=K_p e(t) + K_i \; e(t) dt$

Where,
e (t) is the speed error
M(t) is the output of the controller
Kp is the proportional constant
Ki is the integral constant

Here the controller provides an appropriate feedback to the system based on the error signal. This feedback takes account of the magnitude as well as its rate of change and integral effect.

3. Results and Analysis

This Experimental Results deals with hardware implementation for Brushless DC motor drive using PIC Microcontroller. The sequence of tasks in hardware implementation is explained as follows. First the hall sensor outputs are detected from the hall sensors. The next step is designing the PIC controller circuit in PCB. The PIC coding is programmed next to generate the gate pulses for firing the inverter circuit. The sequence of steps includes the development and testing of power supply board. For implementing the switching pattern three phase inverter is used. The inverter is developed and tested, tested circuits are coupled. The speed control of BLDC motor is experimented. Now in this chapter we have explained the hardware requirements, the respective connection diagrams of different circuits.

3.1. Hardware Requirements

The BLDC drive system consists of following different modules.They are,
1) Power supply module
2) Control signal generation module
3) Inverter module
4) Power MOSFET driver module

3.2. Power Supply Unit

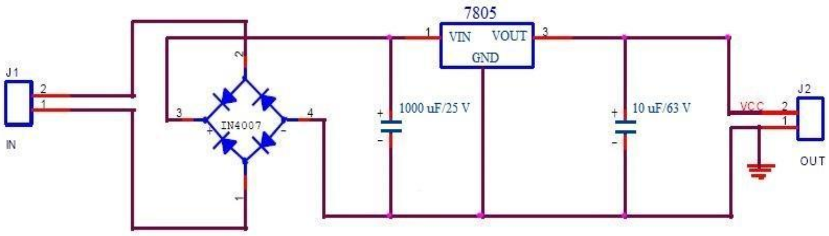

Figure 8. LEAD ACID battery power supply circuit for PIC microcontroller unit

The PIC Microcontroller is supplied with 5 volt. 7805 IC is used for PIC microcontroller unit power supply circuit and

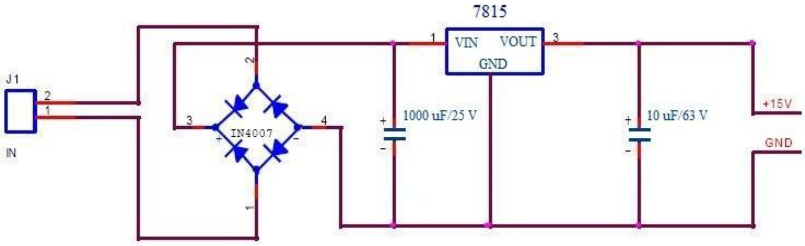

Figure 9. Power supply circuit for driver unit

The driver unit is supplied with 15 volt DC. 7815 IC is used for driver unit power supply circuit.

3.3. Driver Unit

Driver unit is used to generate the gate pulse for Sepic converter and Voltage Source Inverter switches. The Figure 10 shows driver unit for BLDC motor drive system. For isolating the low voltage operated control circuit from the high power circuit called opto-coupler or opto-isolators are used.

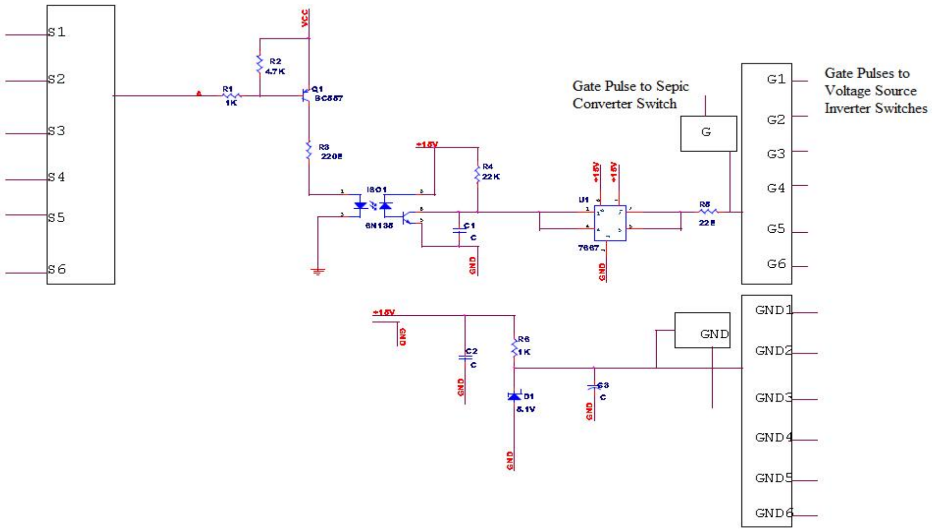

Figure 10. Driver Circuit for proposed BLDCM system

So the opto isolators are used in between the pic microcontroller circuit and the driver circuit. The PIC microcontroller pins from s1 to s6 are used to control the MOSFET gate driver. And the MOSFET gate driver can be generated the gate pulses to each switch of VSI and DC to DC converter.

3.4. Optocoupler

The optically coupled isolator or opto coupler was the device which contains at least one emitter which is optically coupled to a photo detector through somesort of an isolating medium. This arrangement permits the passage of information from one which contains the emitter to the other circuit passed optically across an insulating gap; the transfer is one way that is the detector cannot affect the input circuit. This is important because the emitter may be driven by a low voltage circuit utilizing logic gates which the output of the photo detector may be part of a high voltage dc or ac. Opto isolator typically comes in a small 6-pin or 8-pin IC package, but is essentially a combination of two distinct devices: an optical transmitter, typically a gallium arsenide LED (light-emitting diode) and an optical receiver such as a phototransistor or light-triggered diac. The two are separated by a transparent barrier which blocks any electrical current flow between the two, but does allow the passage of light. The basic idea is shown, along with the usual circuit symbol for an opto isolator.The 6N135 opto isolator consists of a light-emitting diode and an integrated photon detector composed of a photodiode and an open-collector output transistor. Separate connections are provided for the photodiode bias and the transistor-collector output.

3.5. PIC 16F877A Microcontroller

The PIC 16F877A Microcontroller [3] is the prime controller of this project. It controls the operation of Sepic converter and Voltage Source Inverter associated in this project. The PIC 16F877A microcontroller gives control signal to the MOSFET drive circuit. The various features present in this PIC16F877A helps to achieve an effective control over BLDC Motor drive.

According to gate pulses generated from the driver circuit with the help of PIC microcontroller, the voltage source inverter will switch at the regular time interval. Thus the speed control of the BLDC motor can be achieved using PIC microcontroller.

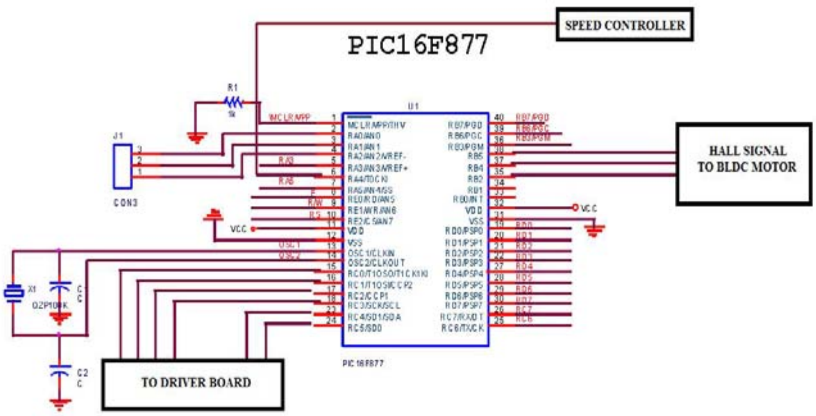

Figure 11. PIC16F877A microcontroller

3.6. Power Circuit of BLDC Motor Drive

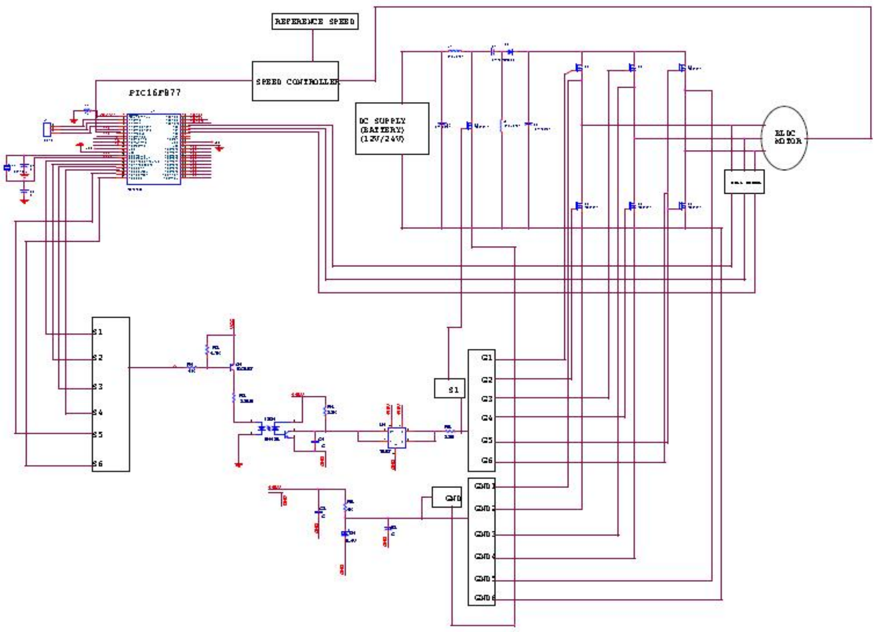

Figure 12. Entire power circuit of BLDCM drive

The power circuit of overall system is shown in the Figure 12. The 12 volt DC supply is given to the sepic converter from the battery. The 12 volt DC is converted into 24 volt DC by using DC to DC converter called Sepic converter. And then the converted DC voltage is given to the VSI where the DC is converted into AC. Now the AC supply is given to the BLDC motor. The hall sensor is used to sense the speed of the motor. BLDC motors use electronic commutation instead of mechanical commutation to control the power distribution to the motor. Hall-effect sensors, mounted in the motor, are used to measure the motor"s position, which is communicated to the micro controller to spin the motor at the right time and right orientation.

4. Results and Discussion

The Microcontroller based BLDC motor drive system is a very popular device in AC power drives. This chapter discusses about the usage of solar energy to power up for commercial appliances. In order to achieve the required voltage, the Photo Voltaic (PV) Module may be connected either in parallel or series, but its costlier. Thus to make it cost effective; power converters and batteries are been used. The electrical charge [3] is consolidated from the PV panel and directed to the output terminals to produce low voltage (Direct Current). The charge controllers direct this power acquired from the solar panel to the batteries. The voltage is then boosted up using the SEPIC [5] power converter, ultimately running the BLDC motor which is used as the drive motor for our commercial application. In the course work, the characteristic features of the microcontroller based BLDC motor drive for commercial applications were studied and also were modeled individually using MATLAB/SIMULINK and the complete hardware integration of the system is tested to meet up the application’s requirement.

4.1. Simulation and Experimental Results of BLDC Motor Drive System

After running the simulation, the speed, torque [4], current, input and output power waveforms were recorded and analysed using m-file. The below figures show the waveforms of the electrical and mechanical quantities after the stator was supplied with a desired sinusoidal voltage and frequency.

4.1.1. Power Supply Unit

Figure 12 shows the power supply to the PIC16F877A microcontroller. From the result, it is known that the power supply unit gives voltage of about 5 V to the PIC microcontroller unit.

Figure 13 shows the power supply to the driver unit. From the result, it is found that the power supply unit provides voltage of about 15 V to the driver unit.

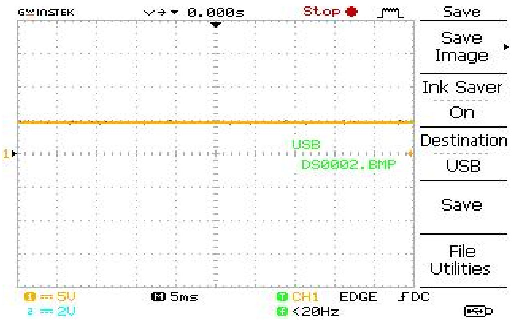

Figure 12. Power supply to PIC16F877A microcontroller

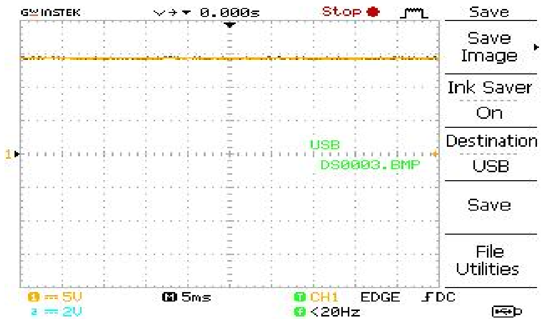

Figure 13. Power supply to driver unit

4.1.2. Gate Pulse Generation of Sepic Converter Switch

Figure 14. Gate Pulse to Sepic Converter Switch

A DC-to-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. DC to DC converters are important in portable electronic devices, which are supplied with power from batteries primarily. The power semiconductor device used in this project is MOSFET. This device operates like a switch. When the switch is off, no current can flow. Current flows through the load when switch is “on”. The figure 14 shows the gate pulse to the sepic converter switch (MOSFET). Usually, this is applied to control the output voltage, though it could be applied to control the input current, the output current, or maintain a constant power.

4.1.3. Gate Pulse Generation of Voltage Source Inverter

The Figure 15 to 20 shows the gate pulse to the Voltage Source Inverter (VSI). Switch 1, switch 2, switch 3, switch 4, switch 5 and switch 6.

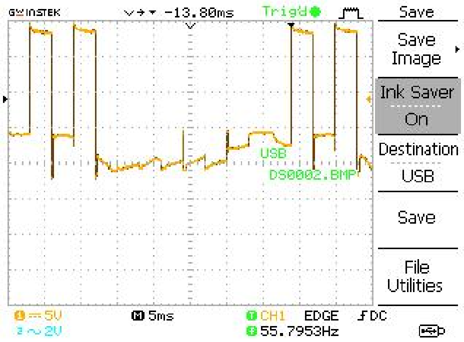

Figure 15. Gate Pulse to VSI Switch S1

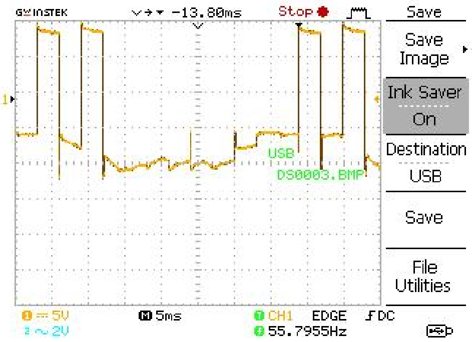

Figure 16. Gate Pulse to VSI Switch S2

Figure 17. Gate Pulse to VSI Switch S3

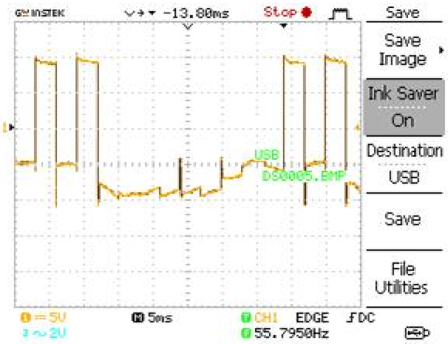

Figure 18. Gate Pulse to VSI Switch S4

Figure 19. Gate Pulse to VSI Switch S5

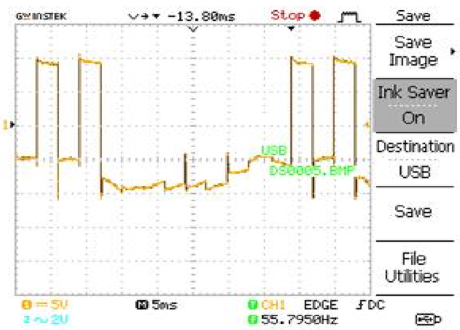

Figure 20. Gate Pulse to VSI Switch S6

4.1.4. BLDC Motor Fed by VSI

The Figure 21 to 22 shows the simulation and experimental results ofsupply voltage of BLDC motor drive system.

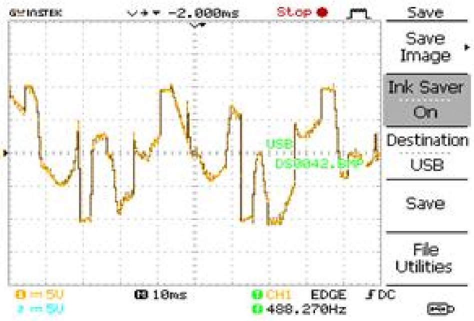

Figure 21. Hardware result of output Voltage (Vab) of VSI

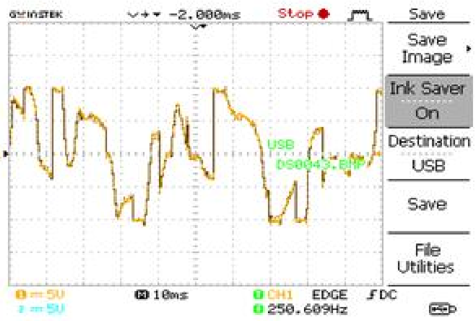

Figure 22. Hardware result of output Voltage (Vbc) of VSI

Figure 23. Hardware result of output voltages of VSI

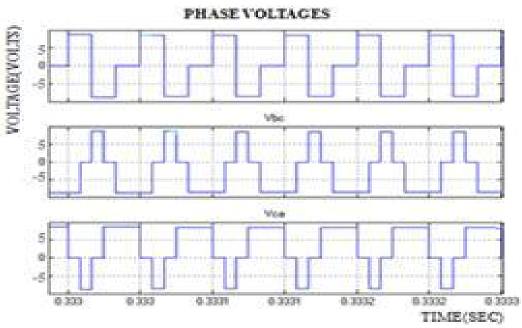

Figure 24. Simulation result of output Voltage (Vca) of VSI

4.1.5. Rotor Speed of BLDC Motor

The Figure 25 & 26 shows the speed of the Proposed BLDC motor drive. The speed of motor is 1800 rpm.The simulation result can be done by using MATLAB/SIMULINK.

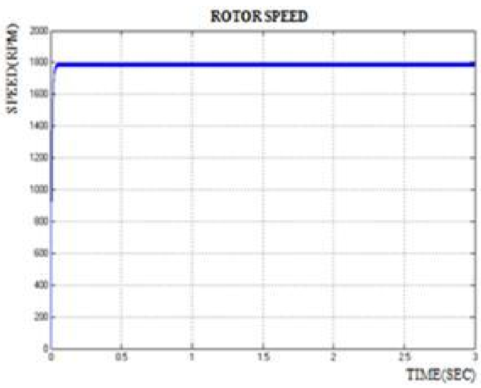

Figure 25. In simulation - Rotor Speed of BLDC Motor

Figure 26. In hardware - Rotor Speed of BLDC Motor

4.2. Hardware Model BLDCM Drive

The Figure 27 shows the experimental result of rotor speed of the BLDC motor. In hardware experimental result the speed of the rotor is measured by using tachometer.

Figure 27. Hardware Model of BLDC motor drive system

The Figure 27 shows the experimental model of the BLDC motor drive system. The 12 V battery, sepic converter and VSI (Voltage Source Inverter) fed BLDC motor are connected in a single board and results were analysed using Digital Scope Osilloscope in our research laboratory.

References

[1] Hong-xing Wu, Shu-kang Cheng, Shu-mei Cui. A Controller of Brushless DC Motor for Electric Vehicle. *IEEE Transactions on Magnetics*. 2005; 41(1).
[2] Immanuel Alphonse, Dr S HosiminThilagar, F Bright Singh. Design of Solar Powered BLDC Motor Driven Electric Vehicle. *International Journal of Renewable Energy Research*. 2007.
[3] Joon Sung Park, Jung- Moo, Jin-Hong Choi. Development of BLDC Motor and Drive Module for Automotive Application. *IEEE Vechile Power and Propulsion Conference*. 2012.
[4] Liu Mingji, Guo Hanjin, Song Meihong, IEEE member. *Ripple Torque Analysis and Simulation of BLDC Motor*. International Power Electronics and Motion Control Conference. 2012.
[5] Mokhtar Ali, Mohamed Orabi. Design Consideration Of Modified Sepic Convert For Led Lamp Driver. *IEEE International Symposium on Power Electronics for Distributed Generation Systems*. 2010.
[6] Phaneendra Babu Bobba, KR Rajagopal. *Modeling and Analysis of Hybrid Energy Storage Systems used in Electric Vehicles*. IEEE International Conference on Power Electronics Drives and Energy Systems. 2012.
[7] Rahul Khopkar, SM Madan, Masoud HaJiaghajani, Hamid A Toliyat. A Low-Cost BLDC Motor Drive Using Buck-Boost Converter for Residential and Commercial Applications. *IEEE Transaction on Power Electronics*. 2002.
[8] Vivek Naithani, AN Tiwari, Smita Dobhal. Simulation of Sepic Converter Fed Leds. *International Journal of Engineering Science and Technology*. 2009.